From Appropriate to Green to Sustainable -- Co-Designing /Co-Evolving for Development

environment

society

economy

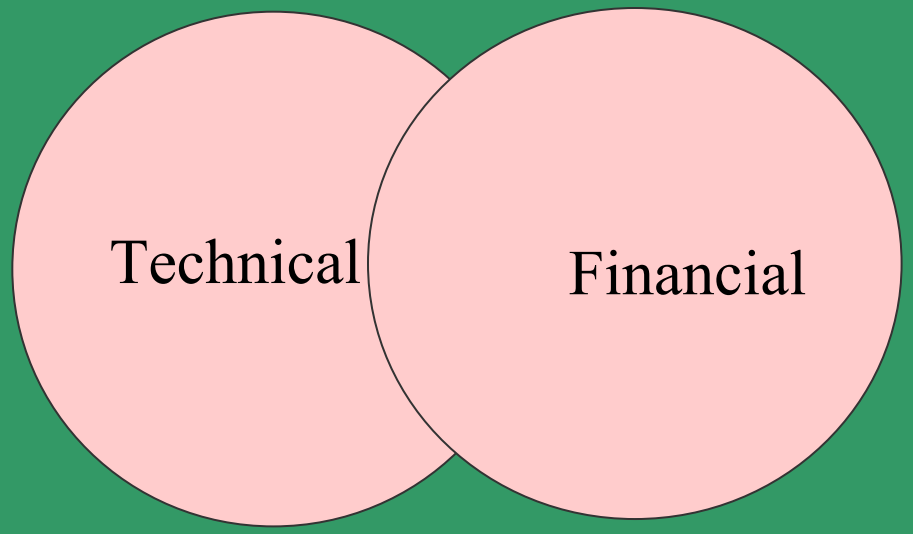
"Development, Design and Dissemination" (SP.722)

April 4, 2005

Susan Murcott
Dept. of Civil and Environmental Eng.
Massachusetts Institute of Technology

Back in the days of the 20th century, Western engineering design was comparatively simple:

- Technical Criteria
- Economic/Financial Criteria (Cost-Benefit Analysis)



“Appropriate Technology”

- 1973 - Publication of E. F. Schumacher’s Small is Beautiful
- A different value system based on
  - Meeting Human Needs
  - Human Capital/Job Creation
  - Equity
  - Developing Countries

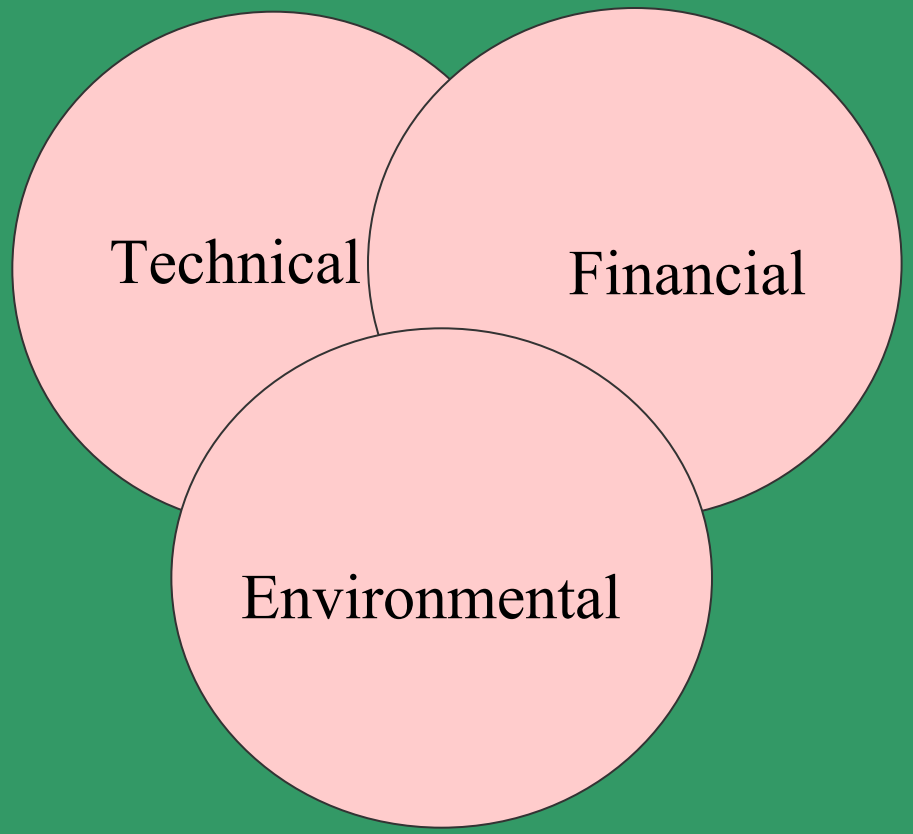
Design Principles for Appropriate Technology

(after E.F.Schumacher: Small is Beautiful, 1973)

1. Simple design & production
2. Low cost
3. Use local materials for local use
4. Rural focus: Technologies and workplaces must be created in areas where people are living now, not primarily in urban areas

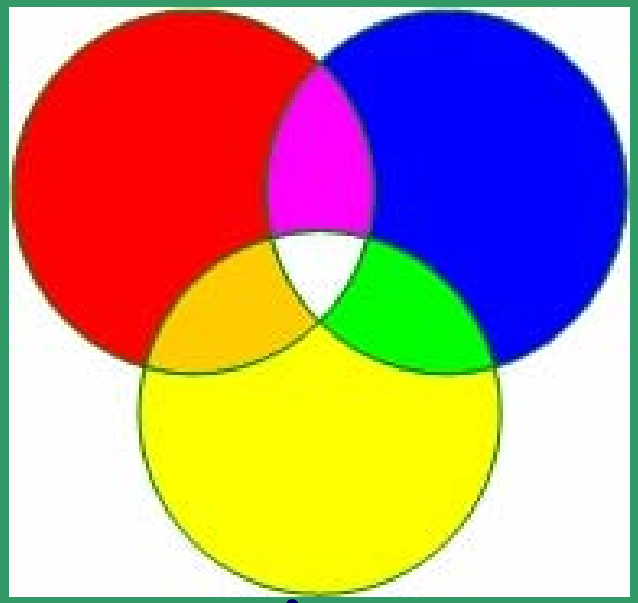
Environmental Awareness, codified into laws and regulations beginning in the 1960s in the U.S., added another dimension:

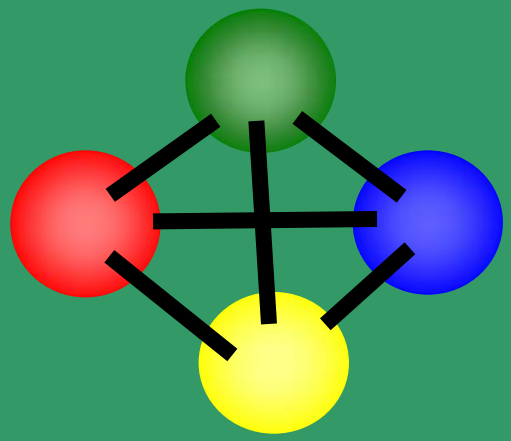
- Technical
- Economic/Financial Criteria (Cost-Benefit Analysis)
- Environmental / Green Design

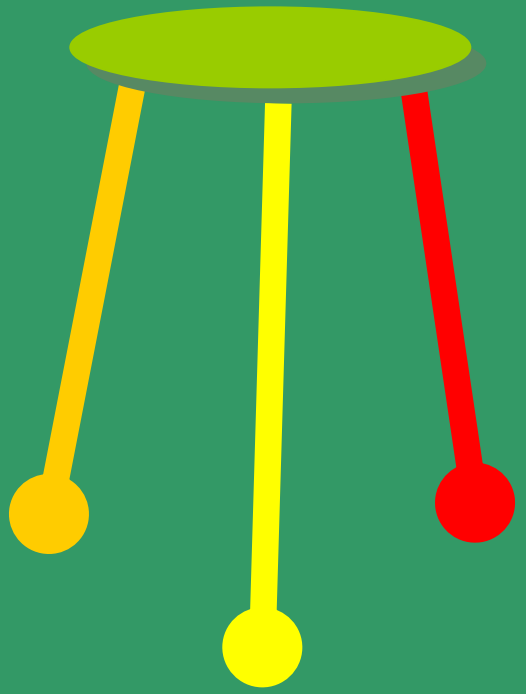


"Sustainable development" has 2 widely accepted meanings:

Balance: economic, social, environmental aspects



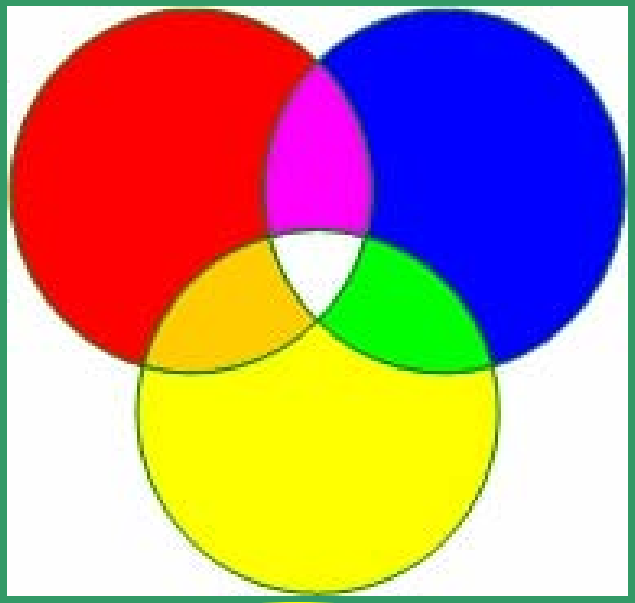




Equity…"meeting the needs of the present without compromising the ability of future generations to meet their own needs."

- Our Common Future, 1987

"Engineering design for sustainable development" framework



Financial /Economic

*** Cost, subsidies, taxes, profitability, etc.**

•Provides local jobs?

•Supports local economies?

Technical

• Standards and Guidelines

• Quality Assurance/Quality Control

• Operation and Maintenance

• Materials/parts availability

Social

• Customer satisfaction

•Simple/convenient/user friendly

• Durable

The Design Process (standard textbook version)

- Problem Definition
- Idea Generation
- Information Gathering
- Concept Evaluation
- Lab Research, Experimentation & Analysis
- Detail Design
- Fabrication
- Testing & Evaluation (Lab and Field)

Who needs development… us or them?

Drinking water for car washing?

Photo removed for copyright reasons.

Carrying water for basic needs?

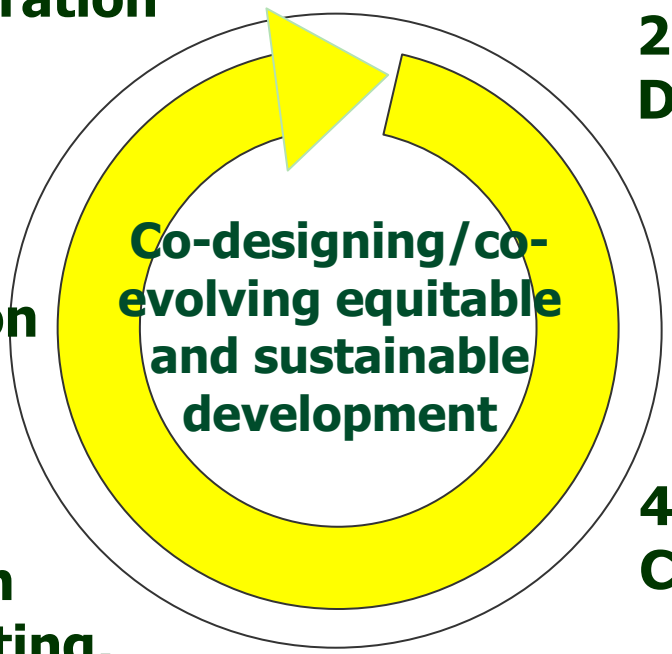
Photo removed for copyright reasons.

We must work in Partnership

Co-Designing /
Co-Evolving

Design for Development

Co-Designing/Co-evolving for Development (an iterative process)



1. Problem Awareness through Partnership

2. Problem Co-Definition

3. Idea Co-Generation

4. Concept Co-Evaluation

5. Field Experience, Fabrication, Experiment, Lab Work, Analysis

6. Refined Design (Field and lab testing, multiple sites, multiple countries)

7. Pilot studies

8. Implementation

9 Scale-up

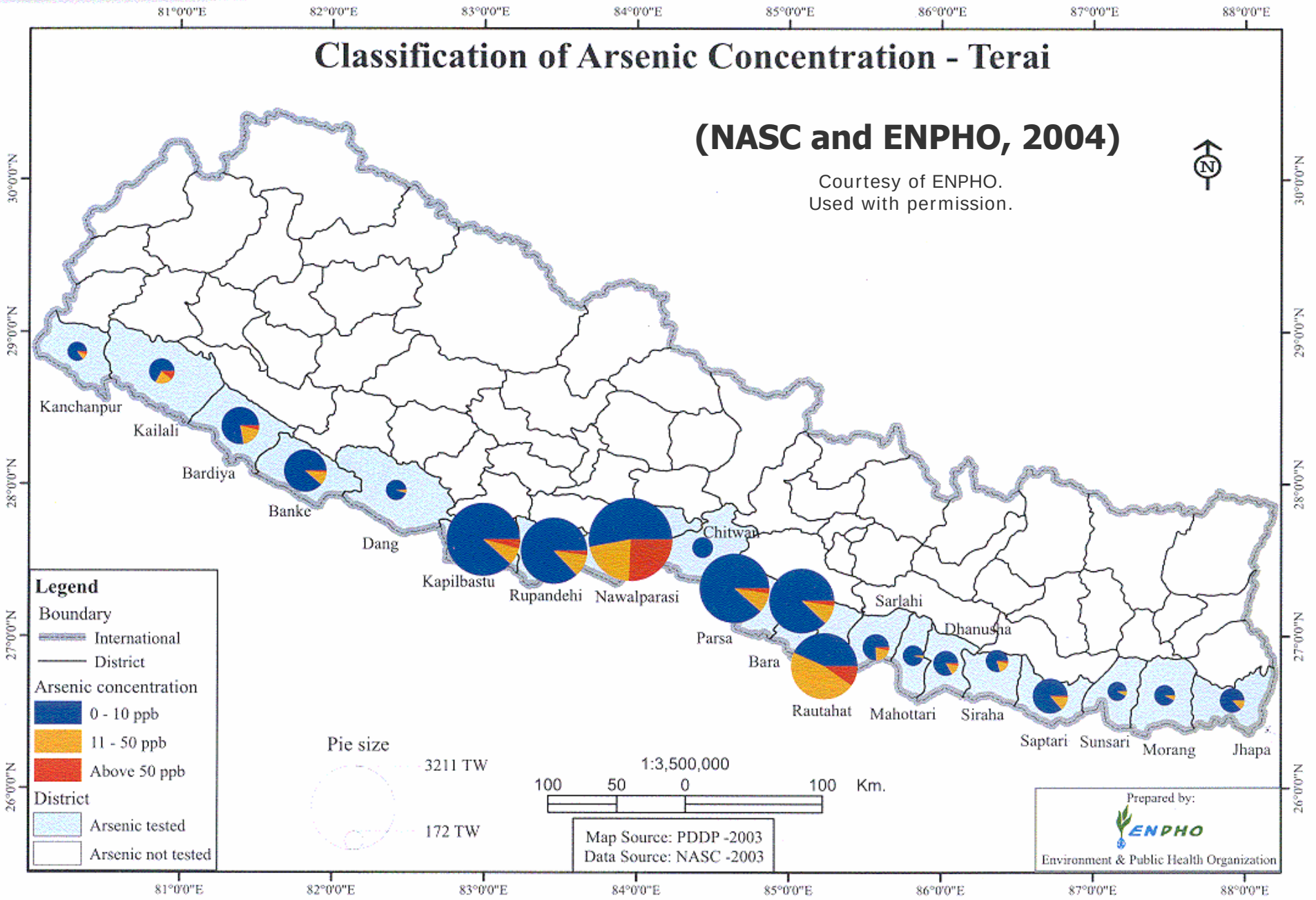
10. Reiteration / Reinvention

(1) Problem Awareness through Partnership

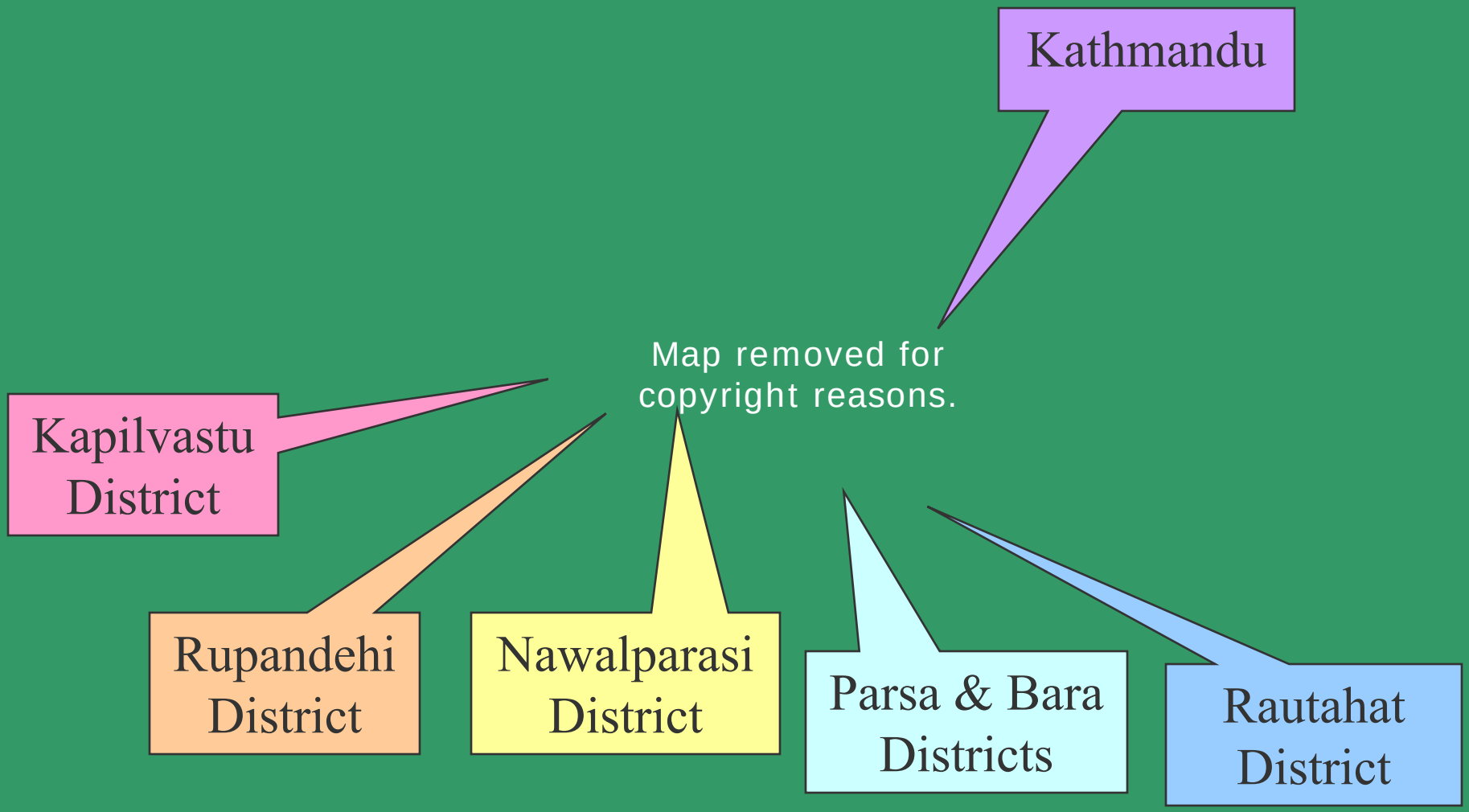
Problem Awareness - Arsenic in South Asia

Pre-1970s:	Surface water for drinking, caused many diseases
1970s:	Groundwater was tapped as a safe, pathogen-free alternative for drinking
1980s:	Naturally occurring arsenic found in groundwater
1990s:	Millions of people found affected, serious disaster

Example: Arsenic in Nepal



MIT Nepal Water Project Field Sites



Problem Awareness – Arsenic

- Source: Natural
- Toxicology
  - Poison
  - Skin disease such as melanosis, keratosis
  - Vasular diseases
  - Cancer to lung, bladder

Photo removed for copyright reasons.

- World Health Organization guideline: 10 ppb
- Nepali interim guideline: 50 ppb
- Nepal Terai Region

  25% tubewells >10 ppb (1.7 million people)

  8% tubewells >50 ppb (0.5-0.7 million people)

Skin Diseases: Melanosis and Keratosis

Photos removed for copyright reasons.

Partners in Nepal

- Environment and Public Health Organization (ENPHO)
- Rural Water Supply and Sanitation Support Programme (RWSSSP)

(2) Problem Co-Definition

Problem Co-Definition

•Our proposal is to design a household drinking water treatment unit to remove arsenic and pathogens;

•Technical Performance: Remove arsenic, bacteria and parasites to National Standards or WHO Guidelines;

• Water Quantity: The flow rate should be > 10 L/hour;

• Cost: The cost/unit should be < $30. Yearly replacement parts <$2, designed for rural areas and urban slums for those who earn <$2/day;

• Manufacturing: Produced by local people, using locally available materials, creating local jobs;

• User friendly: Socially acceptable to women and children users.

Problem Co-Definition
Arsenic Technology Database

Gather information for 50+ technologies:

- Arsenic removal mechanisms (physical, chemical, etc)
- Technical performance
- Construction, operation and maintenance
- Cost
- Flow rate
- Strengths, weakness, limitations

http://web.mit.edu/murcott/www/arsenic

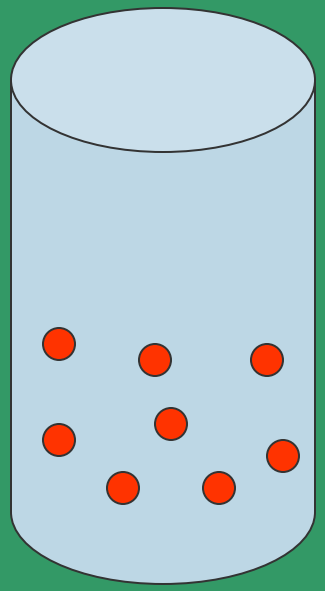
(3) Idea Co-Generation
8 Arsenic Removal Technologies

- (1) 3 *Kolshi* (in Nepali = 3 *Gagri* with zero valent iron filings);
- (2) Iron filings in jerry can;
- (3) Coagulation/Filtration (2-*Kolshi* based on Chakraborti's arsenic removal system);
- (4) Iron oxide coated sand;
- (5) Activated alumina metal oxide #1 (Apyron Inc.);
- (6) Activated alumina metal oxide #2 (Aquatic Treatment Systems Inc.);
- (7) Arsenic treatment plant;
- (8) *Kanchan*^{TM} Arsenic Filter

Three-Kolshi (Gagri) System

Jerry Can

1. Fill 10 L plastic jug with raw water.



2. Add iron filings

3. Wait 3 hours

4. Decant treated water

Coagulation/Filtration (2-Kolshi)

Chemical packet

Raw Water

Mixing & Settling

Filtration

Treated Water

Iron Oxide Coated Sand (IOCS)

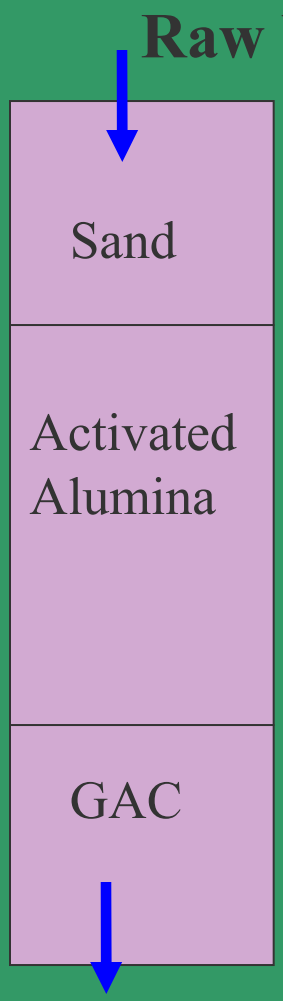
Raw Water

Sand and gravel

Iron Oxide Coated Sand (IOCS)

Treated Water

Activated Alumina Metal Oxide #1
(Apyron Aqua-Bind Media)



Activated Alumina Metal Oxide #2

(Aquatic Treatment Systems, Inc.)

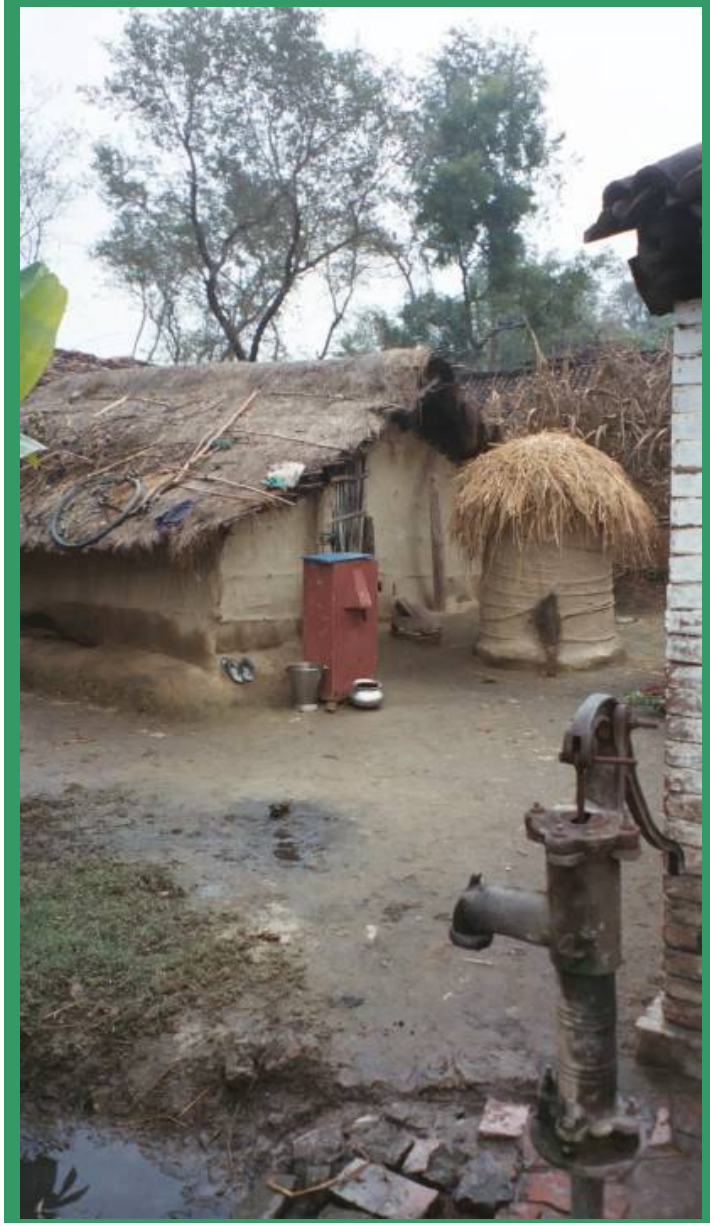
Raw Water

Alumina Manganese Oxide (A/M)

Treated Water

Arsenic Treatment Plants (ATPs)

Kanchan™ Arsenic Filter (KAF)



Courtesy of Tommy Ngai. Used with permission.

(4) Concept Co-Evaluation

is based on...

- Principles/values (also passions and instincts)
- Relationship with local community and partners
- Criteria: “a standard, rule or test on which a decision can be based”
- Metrics = indicators, both quantitative and qualitative.

Design Concept Co-Evaluation Matrix

(also known as a "Pugh Chart")

	Datum	Option 1	Option 2	Option 3
Evaluation Criteria	3-Kolshi	Coagu-lation Filtra-tion	Activated Alumina	Iron-coated sand
Water quality	0	o	-	0
Water quantity	0	+	+	0
Capital cost	0	+	+	+
O&M cost	0	+	+	+
Local jobs	0	+	0	+
User friendly	0	+	-	+
Total	0	+5	+1	+4

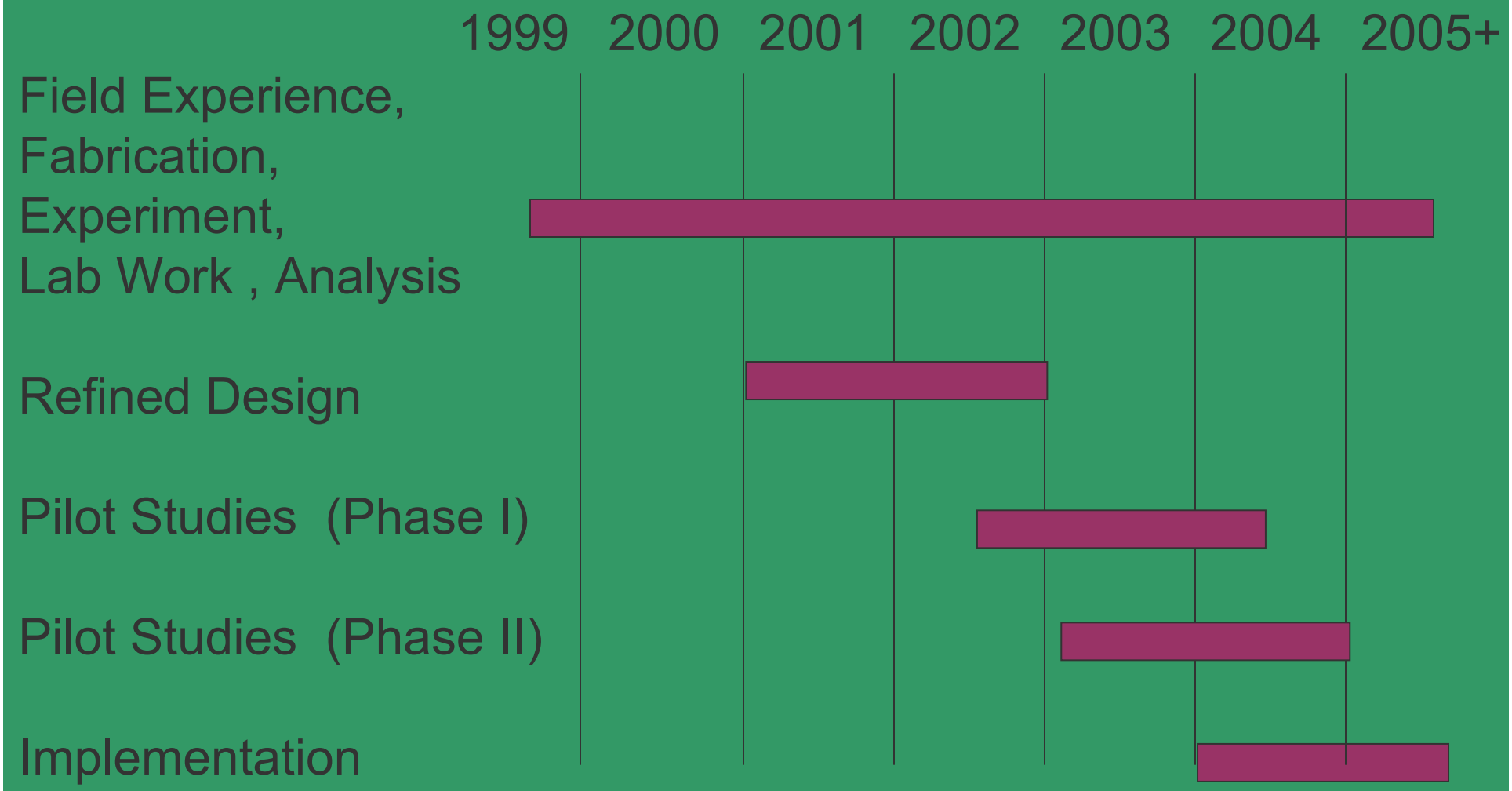
(5) Field Experience, Fabrication, Experiment, Lab Work, Analysis

Engagement with:

- local people and partners,
- local environment
- the problem and solutions

Photos removed for copyright reasons.

Stages of Arsenic Mitigation in Nepal



(6) Refined Design: Phase I Evaluation

Courtesy of Jessica Hurd. Used with permission.

Courtesy of Tommy Ngai. Used with permission.

Phase I Evaluation

1. Preliminary screening of technologies in database/ website.
2. Select 8 technologies to be field tested against following criteria:

Photo removed for copyright reasons.

Technical Performance:

- Arsenic reduced to acceptable level?
- Flow rate sufficient for a large family?

Social Acceptability:

- Easily constructed by local labour using local materials?
- Simple to use and maintain?
- Accepted by Nepali tradition and culture?

Low Cost:

- Affordable to rural villagers?

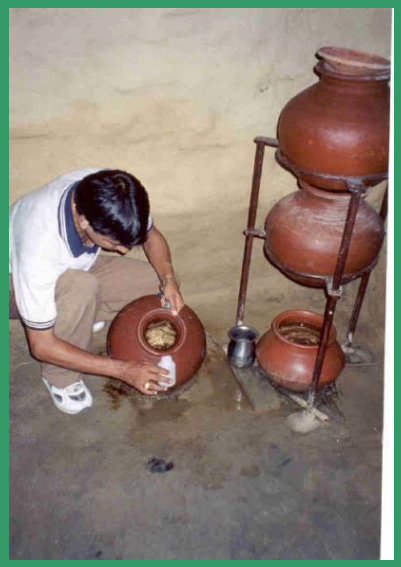
Some Sustainability Design Criteria for MIT H2O-1B Master of Engineering Projects

1. Technical: Meet World Health Organization guidelines for arsenic and microbial removal
2. Social: customer satisfaction, specifically systems acceptable to women who are the typical household managers of water.
3. Financial: affordable to people earning $1/day

Phase I Evaluation Summary

Technology	Technical	Social	Cost	Recommend for Phase II?
3-Kolshi	✓	✓	✓	✓
Jerry Can	✗	✗	✓	✗
Iron Coated Sand	✓	✗	✓	✗
Alumina #1	✓	✗	✗	✗
Alumina #2	✓	✗	✓	✗
2-Kolshi	✓	✓	✓	✓
Treatment Plants	✗	✗	✓	✗
AKF	✓	✓	✓	✓

(7) Pilot Studies
Phase II Evaluation



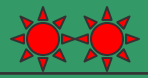
Phase II Pilot Studies of 3 Technologies

3 Kolshi

Coagulation/ filtration System (2-Kolshi)

Kanchan^{TM} Arsenic Filter (KAF)

Phase II Evaluation Summary

	3-Kolshi	2-Kolshi	AKF
Arsenic removal	95-99%	80-90%	90-95%
Iron removal	Not tested	Not tested	93-99%
Flow rate	3-5L/hr	1-5L/hr	10-15L/hr
Materials availability			
Easy construction			
Simple O&M			
Long-term sustainability			
User acceptance			
Low initial cost			
Low running cost			
Overall Ranking	**2nd**	**3rd**	**Best**

 **= poor**  **= moderate**  **= good**

KAF Pilot Study Results (n=16)

Technical Indicators	Average Results
Arsenic Removal	93 %
Total Coliform Removal	58 %
E. Coli Removal	64 %
Iron Removal	93 %
Flow Rate	14 L/hr

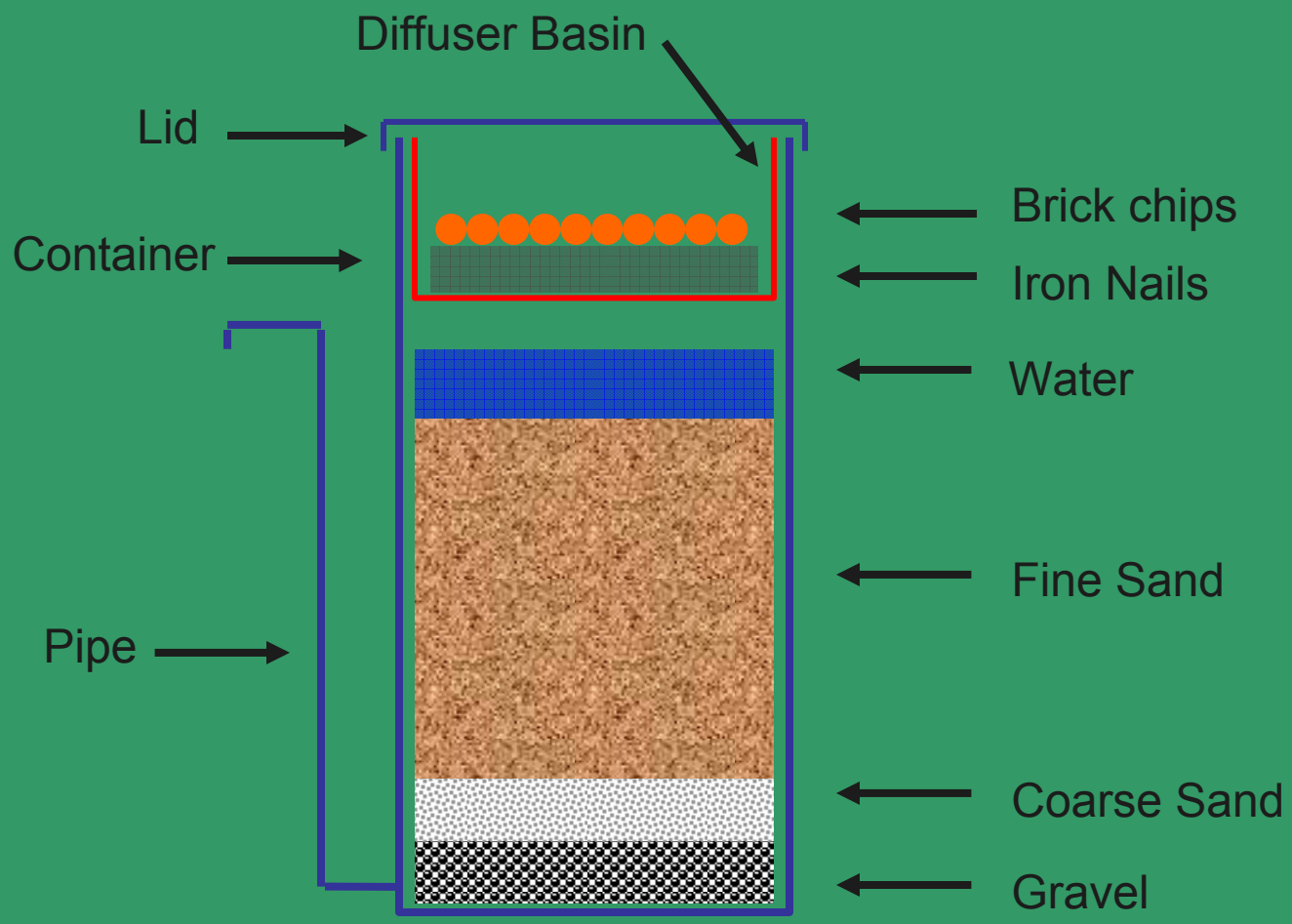
(8 – 10) Implementation, Scale-up, Reiteration, Reinvention

Kanchan^{TM} Arsenic Filter (KAF)

Kanchan™ Arsenic Filter

- Developed in Nepal and at MIT based on improvement on the Biosand Filter
- Intended for arsenic and bacteria removal
- Constructed with easily available local materials
- Manufactured by trained local technicians
- Adequate flow rate for a large family (15L/hr)
- No chemical additives
- No replacement parts except iron nails
- Easy to operate and clean

Kanchan™ Arsenic Filter Cross Section

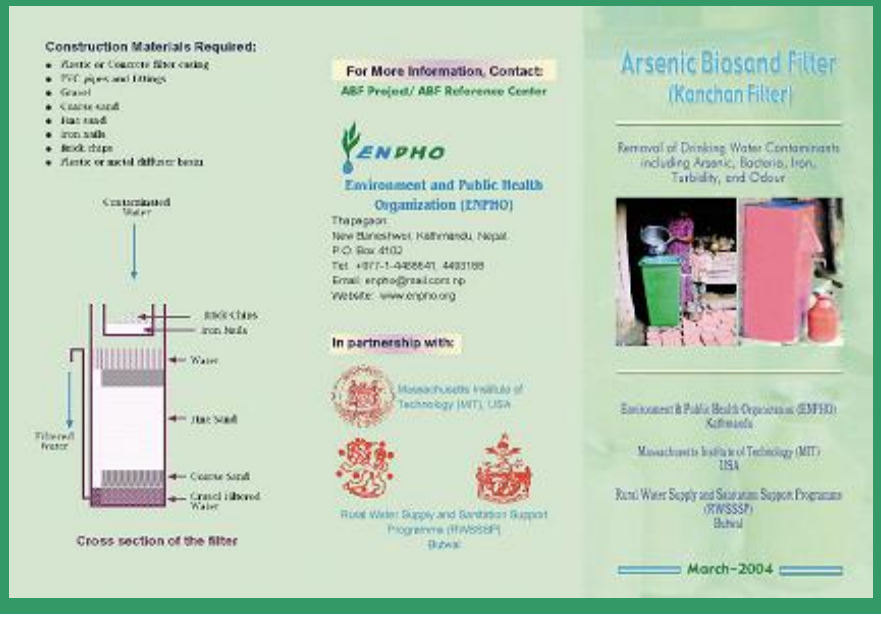


Major Accomplishments

1. Established an in-country KAF Reference and Resource Center at ENPHO to coordinate implementation efforts

- Maintains library and databased of latest technology information and IEC materials, including project locations, progress and evaluations
- Provides training and technical assistance

Courtesy of ENPHO. Used with permission.



Major Accomplishments

2. Researched and developed the Gem505 Design

→ better performance, lower cost, improved acceptance

Concrete Square (2002)

Concrete Round (2003)

Plastic Hilltake (2003)

Plastic Gem505 (2004)

Major Accomplishments

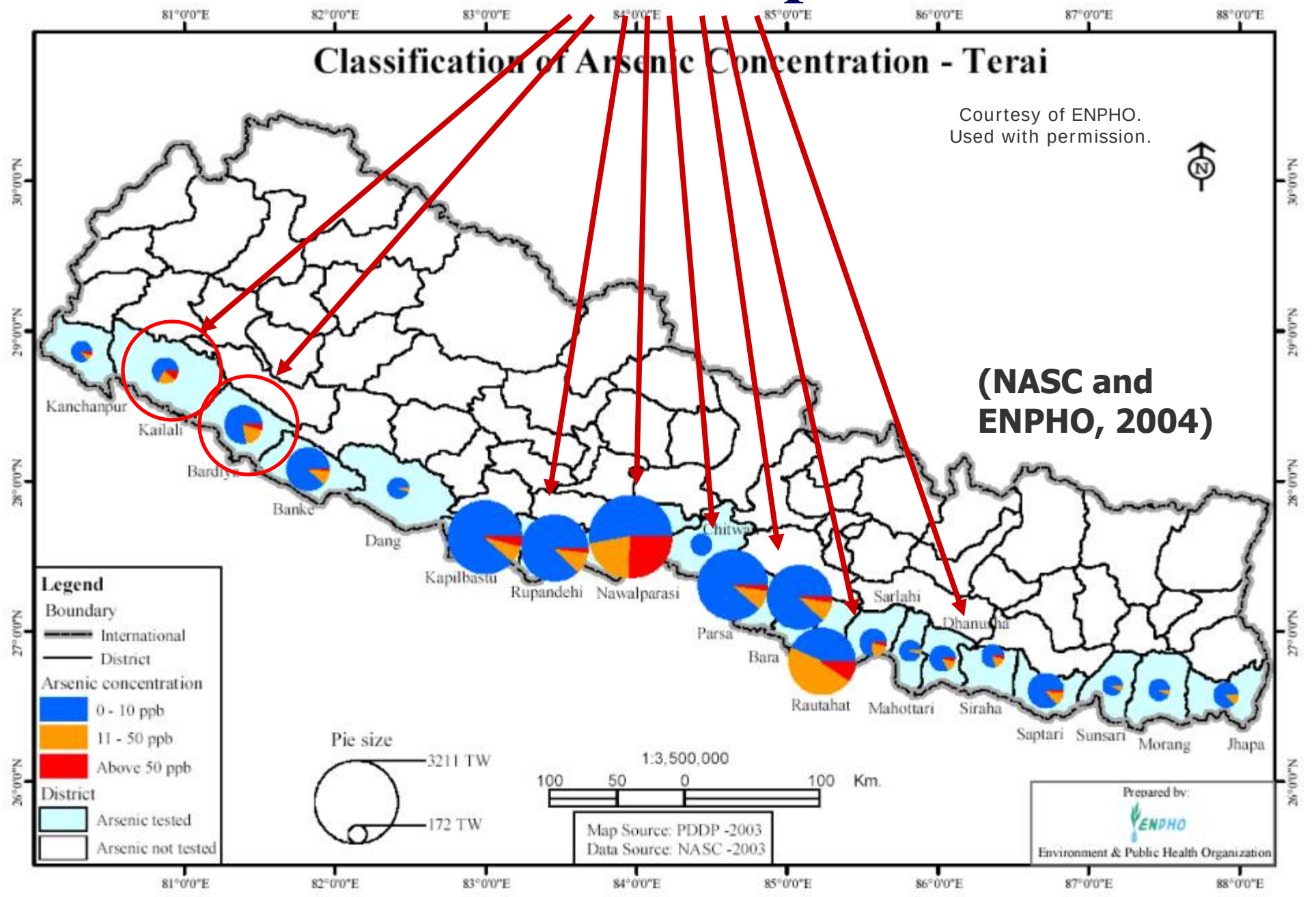
3. ***Train 15 local entrepreneurs from arsenic-affected districts on filter construction, troubleshooting, water testing***

Selected based on SOA2003 and Nepal Census 2001 data including:

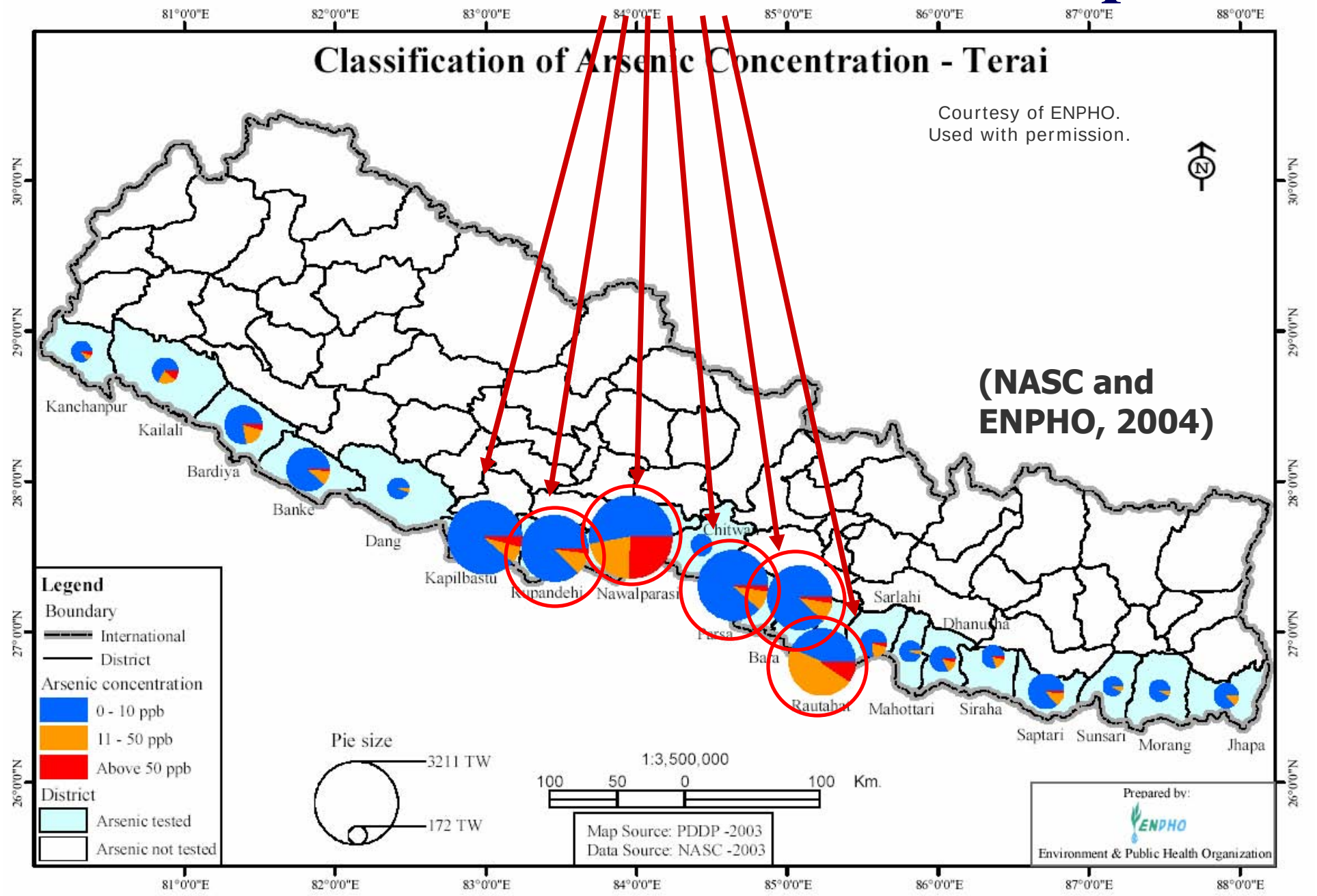
- Population affected
- GPS mapping
- Vulnerability
- Household income
- Arsenic awareness level
- Literacy level
- Health statistics

4. ***Conduct workshops to 30 VDCs and 178 wards on health, water management, treatment options, and filter information***

Location of Entrepreneurs



VDC and Ward-level Workshops



Major Accomplishments

5. ***Over 2,000 filters distributed, serving 15,000+ beneficiaries (as of Jan., 2005)***

RWSSSP distribution (since 2002)	700+
Nepal Red Cross Society distribution (since 2003)	500+
DM project distribution (since April 2004)	350+
Entrepreneurs (since April 2004)	450+

Project Findings

Preliminary User Survey Results

Preliminary results (n= 424) as of Jan 31, 2005

	Yes	*Partially*	*No*
Filter still in operation after 1 year	85.3%	8.3%	6.3%
Users think filter operation is easy	73.6%	---	26.4%
Users can operate the filter correctly	50.2%	42.3%	7.4%
Users will recommend filter to others	82.5%	---	17.5%

	Better	*Same*	*Worse*
Appearance of filtered water	92.8%	6.9%	0.2%
Taste of filtered water	95.0%	5.0%	0%
Smell of filtered water	89.9%	11.1%	0%
Users' perceived health conditions after drinking filtered water	77.5%	22.5%	0%

Kanchan™ Arsenic Filter Monitoring

Arsenic Removal (n=966)

Effluent Arsenic Concentration (ug/L)

Influent Arsenic Concentration (ug/L)	ND	10	20	30	40	50	60	70	80	90	100	150	200	250	300	350	400	450	500
500	5	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
450	8	1	2	3	0	0	0	0	0	0	1	0	0	0	1	1	1	3	
400	10	2	2	1	2	0	0	0	0	0	0	1	0	1	0	0	1		
350	15	3	1	3	1	0	0	0	0	0	0	0	0	0	0	0			
300	28	1	3	1	1	0	0	0	0	0	0	0	0	1	0				
250	27	2	1	2	2	2	0	0	1	0	0	0	1	2					
200	32	1	0	0	0	0	0	0	1	0	1	0	2						
150	40	1	1	0	1	0	0	0	0	0	0	1							
100	99	8	3	1	1	0	0	1	0	0	0								
90	86	6	3	0	0	0	1	2	0	1									
80	57	1	0	1	0	0	0	0	0										
70	42	3	0	3	0	0	0	0											
60	34	13	5	2	1	0	0												
50	71	5	2	0	0	0													
40	21	2	0	0	0														
30	17	0	0	0															
20	44	1	0																
10	12	0																	
ND	189																		

Unacceptable

Acceptable

Figure indicates number of filters

Correct installation and maintenance are highly important

- **NO flexible tubing**
- **NO tap connection**
- **NO dispersed iron nails**

KAF Blanket Monitoring

Iron Removal (n=953)

Effluent Iron Concentration (mg/L)

Influent Iron Conc. (mg/L)	ND	0.1	0.3	0.5	1	2	3	5	10
10	17	1	42	0	62	1	13	6	1
5	47	1	73	0	45	1	1	0	
3	69	0	11	0	1	0	0		
2	32	0	0	0	1	0			
1	210	0	1	0	0				
0.5	26	0	0	0					
0.3	193	0	2						
0.1	2	0							
ND	94								

Figure indicates number of filters

Is this Project:

Appropriate?
Green?
Sustainable?

Co- Evolutionary Technology?

- Filter designed in local environment with local partners

•Filter designed based on collaborative, iterative, multi-disciplinary approached inherent in sustainable development concepts

- Filter designed within social and economic constraint of rural Nepal

- Manufactured by local labor using materials available in rural Nepal

- Easy operation and maintenance

- Filtered water tastes and looks significantly better than untreated water (according to many users) so users like it and are continuing to use it

Sustainable Implementation?

- We select and train entrepreneurs from easily accessible locations

- We provide detailed information to villagers such that they can make individual informed decision to protect their health

- We strengthen the capacity of existing local authorities to support safe water initiatives, rather than relying on remote central authority

- We use existing and functioning distribution networks and infrastructure; therefore reducing risk of failure and negative impacts

Entrepreneurs' Financial Sustainability?

Financially sustainable:
Margin per unit X unit sales > Fixed cost

In our case:

• Fixed cost is minimal because the entrepreneurs are well-established organizations with their own financial support for their premises and staff.

• Temporary staff can be hired to construct filters based on demand

Future Plans and Challenges

- Scale-up from 3,000 units (2005) to reach 0.7M in Nepal
- Increase villagers' awareness of health and water, targeting the poorest, the least educated, and in remote western areas
- Continue to subsidize filters for the poorest villagers
- Provide entrepreneurs refresher training & certification
- Continue research on bacteria, viruses, protozoa removal
- Influence government and policy-makers

Conclusions

- There is no single solution applicable for all regions of Nepal
- Multiple options (e.g. arsenic-free sources options and arsenic removal technologies) are required

- The *Kanchan™* Arsenic Filter is appropriate for the socio-economic conditions of rural Terai region, but other technologies may be more appropriate for other regions/countries

- Even the simplest and best technology will **FAIL, UNLESS** it is supported by an effective implementation plan considering:
    1. User Awareness/Education
    2. Filter Quality Control
    3. Monitoring & Follow-up
    4. Strong coordination

For Further Information

Susan Murcott,
Principal Investigator and Research Engineer
Massachusetts Institute of Technology

Tommy Ngai,
Research Affiliate
Massachusetts Institute of Technology

Roshan Shrestha,
Director
Environment & Public Health Organization

Sophie Walejick
Stanford University

Website:
http://web.mit.edu/watsan

Acknowledgements

In Nepal:

- Environment and Public Health Organization (ENPHO), Kathmandu
- Rural Water Supply and Sanitation Support Programme (RWSSSP), Butwal
- Nepal Red Cross Society (NRCS)
- Rural Water Supply and Sanitation Fund Development Board (RWSSFDB)
- Department of Education (DOE)
- Department of Water Supply & Sewerage (DWSS)
- Kathmandu University
- Tribhuvan University

Internationally:

- MIT Department of Civil and Environmental Engineering, Master of Engineering Program
- MIT IDEAS Competition and Lemelson Foundation
- The World Bank
- Centre for Affordable Water and Sanitation Technology
- University of Calgary, Canada
- University of Texas at Dallas
- Japanese Red Cross Society (JRCS)

Women who carry the water

Thank You

Filter Operation

1. Pour water into top basin. Water will pass through filter and flow up the pipe
2. Collect filtered water at the pipe outlet
3. If flow rate is insufficient, then cleaning is required

Filter Cleaning/ Maintenance

Wash your hands with soap

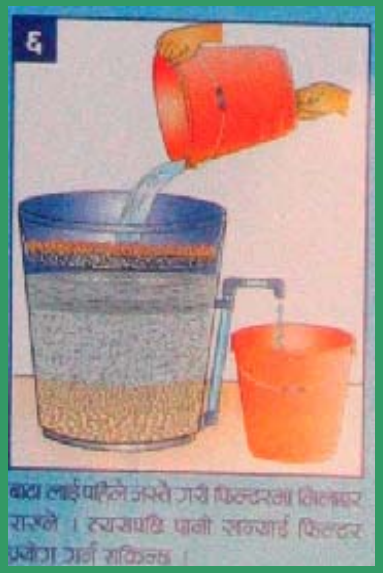
Remove diffuser basin

Stir the uppermost ½ inch of sand with your fingers

Filter Cleaning/ Maintenance

Remove turbid water with a cup.
Replace the basin and add more water.
Repeat three times total.

Discard the turbid water in a dug hole with some cow dung in it



Now the filter can be used again